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13. ABSTRACT (Maximum 200 words)

This project utilized funds to develop a multi-sensor atmospheric boundary layer (ABL) measurement facility that supplemented an existing array equipment under DOD and UAH ownership. The intent is to make this a long-term facility capable of acquiring detailed ABL measurements throughout the year. Funds were requested to
(a) purchase of a three-beam sodar for high vertical resolution measurement of flows in the lower ABL from 30 to 400 m;
(b) upgrade and enhancement a 915 MHz profiler radar owned by UAH,
(c) purchase a lidar ceilometer,
(d) upgrade a WSR-74C Doppler radar, and
(e) instrument a 30 m tower.
The primary goal is to integrate measurements from these systems with those from other nearby instruments used by the Army for operations on Redstone Arsenal (RSA), including an S-band Doppler primary scientific objective is to examine spatial variability in both the stable and unstable ABL. The evolution and structure of the stable nocturnal ABL has received emphasis in the ensuing research utilizing this equipment.

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Final Progress Report

Defense University Research Instrumentation Program (Topic #21)

Instrumentation for Accelerating Remote Sensing and Analysis of Atmospheric Boundary Layer Structures

DEVELOPMENT OF A MULTI-SENSOR SYSTEM FOR MEASUREMENT OF 4-D ATMOSPHERIC BOUNDARY LAYER STRUCTURES

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1. Statement of the original project goals

We proposed to develop a multi-sensor atmospheric boundary layer (ABL) measurement facility that would add to an existing array equipment under DOD and UAH ownership. The intent was to develop a long-term facility capable of acquiring detailed ABL measurements throughout the year. Funds were requested for the following major items:

(a) Purchase of a three-beam sodar for high vertical resolution measurement of flows in the lower ABL (30 to 400 m).

(b) Upgrade an existing National Weather Service WSR-74C Doppler radar that was to be decommissioned under the NWS modernization program and donated to UAH.

(c) Carry out a minor upgrade and enhancement of the UAH 915 MHz profiler radar.

The aim was to integrate measurements from these systems with those from other nearby instruments used by the Army for operations on Redstone Arsenal (RSA), including an S-band Doppler radar, a network of surface meteorological stations and fixed-site and mobile rawinsonde facilities.

The underlying scientific justification was to utilize this equipment for detailed measurements of boundary layer flows and thermodynamics over a 100-200 km^2 region of Redstone Arsenal and adjacent regions. This region is characterized by a variable surface, including the Tennessee River, wetlands, mixed forested and pasture regions, and flat agricultural regions. A particular focus was to examine spatial variability in both the stable and unstable ABL over heterogeneous surfaces. The evolution and structure of the stable nocturnal ABL has received emphasis in the ensuing research utilizing this equipment.

2. Modifications to the original project goals

The original plan outlined in the previous section was adjusted due to the following three unforeseen circumstances:

- The WSR-74C radar was not (and has not yet been) decommissioned due to political issues beyond our control. Closure of the Huntsville NWS office, originally scheduled for 1997, has been a long process strongly opposed by our Congressman and the local community. It is expected, however, that the radar will be transferred to UAH in the near future (sometime in CY 2001) as this issue is nearing a final resolution.

- Testing of the 915 MHz antenna revealed that a new antenna was required in order to provide high-quality measurements.
- Advances in technology reduced the cost of signal processing cards required for the Doppler radar upgrade (item b).

As a result of the above, the major equipment list was modified as follows:

(b′) The NWS radar was not upgraded, but a signal processing card (PIRAQ), a motion controller, and data acquisition cards were purchased in anticipation of a future upgrade. This upgrade is expected to be finalized in CY 2001.

(c′) The 915 MHz profiler was upgraded with a new antenna, having a tapered beam pattern that was superior to the original antenna beam pattern. A 2 kHz Doppler sodar was purchased from Radian, and was integrated with the 915 MHz profiler such that it would provide the acoustic source for the Radio Acoustic Sounding System (RASS). This is viewed as an improvement over the original design.

(d) A lidar ceilometer (Vaisala CT-25K) was purchased with funds not expended (actually saved) on the radar upgrade. This has been a worthwhile instrument whose performance has exceeded our expectations, as demonstrated in the example below.

(e) A 30-meter tower adjacent to the profiling equipment was instrumented to provide temperature at the 2, 12 and 30-m levels, RH at the 12-m level, and wind at the 12 and 30-m levels.

The three major components (a), (c') and (d) are now termed the Mobile Integrated Profiling System (MIPS), and are collectively a powerful system capable of measuring BL properties. A schematic of the MIPS is shown in Fig. 1. The layout of the network, including the MIPS location, is provided in Fig. 2.

A complete listing of the major equipment components and parts is included in the Appendix.

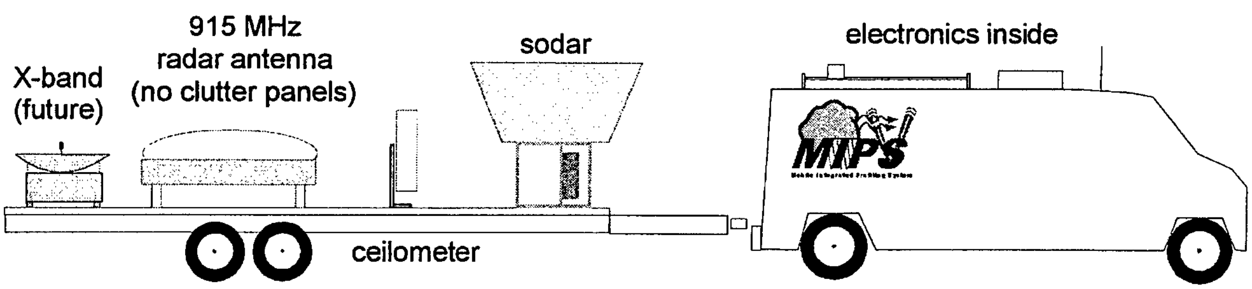

Fig. 1. Components of the Mobile Integrated Profiling System (MIPS)

3. Research utilizing the equipment

Funding to conduct a three-year program on nocturnal boundary layer investigations was acquired through the DePSCOR program. This research is nearing completion, and will result in two M.S. theses and journal papers derived from them. In the following, we present some results of this research which illustrate examples of data collected by each of the instruments purchased under this project. These data were collected on 10 November 1999.

Fig. 2. Locations of instrumentation over Redstone Arsenal. Yellow squares are surface meteorological stations, and the red circle shows the MIPS locations.

Overview

An anticyclone was centered over Georgia, and weak WSW geostrophic flow existed near the surface. Weak subsidence was prevalent over the region during the nocturnal period. Although a surface-based inversion was well established within 4 h of sunset, the flow remained turbulent as indicated by gradient Ri values of 0.25 within the 12-30 m level. Three major turbulent burst events were observed during this night after the NBL inversion was established. The persistent turbulence (low Ri) alluded to above abated near 0400 UTC as Ri values increased temporarily to 1-2. A reduction in Ri to near 0.5 occurred between 0530 and 0600, apparently due to shear-induced turbulence just above the tower level. This represented the first turbulent event. A second turbulent event was associated with a gravity wave ducted by a subsidence inversion within the residual layer. The top of this layer is well defined by enhanced SNR from the 915 MHz profiler (Fig. 3); the gravity wave is marked by a decrease in height of this enhanced layer near 0700-0800 UTC. The residual layer and gravity wave event were also well sampled by the lidar ceilometer (Fig. 4). A third turbulence event was associated with the arrival of a stratocumulus cloud layer that followed the gravity wave. The impact on the NBL, however, was smaller than expected, and the reduction of 12-30 m Ri occurred about 1 h after the cloud deck moved overhead. We are particularly interested in further examining the impact of clouds on the NBL.

915 MHz profiler

This is a 5-beam system that is well suited to measure winds 110 m upwards to 1-5 km. The return power field contains information on the refractive index structure function, C_n^2, which defines elevated stable layers (Fig. 3) and will be used in conjunction with a passive 12-channel microwave radiometer to refine and sharpen the retrieval of temperature and water vapor profiles.

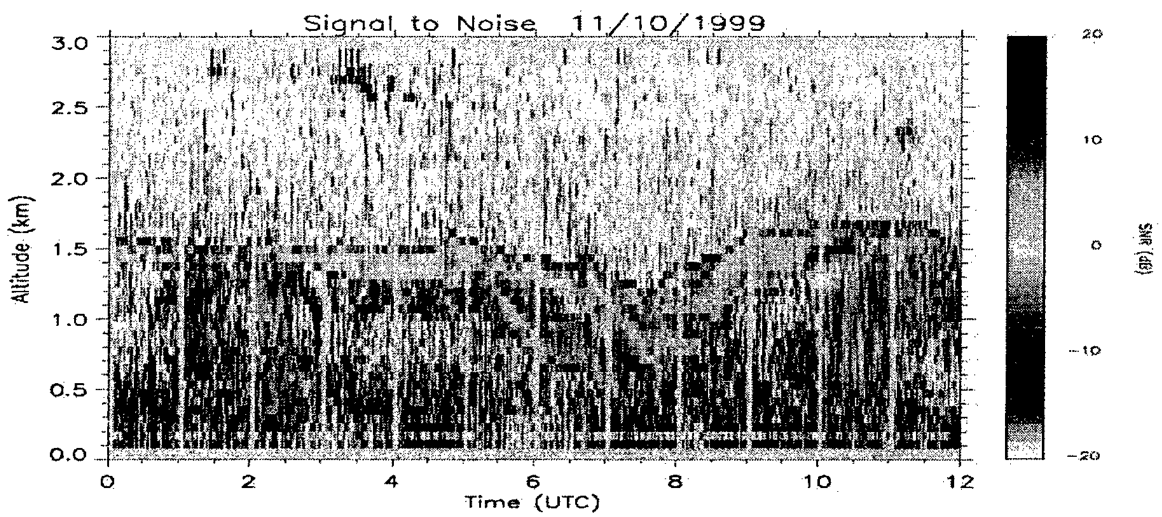

Fig. 3. Time vs. height section of 915 MHz profiler return power

Lidar ceilometer

The relatively high sensitivity of this instrument, which was greater than expected, reveals the depth of the CBL, residual layer, and other fine-scale features as shown near the 500 m level between 0000 and 0400 UTC (Fig. 4). On other evenings, the ceilometer has revealed the presence of solitary Kelvin Helmholtz billows early in the life cycle of the NBL. It also measures cloud base and cloud properties (which was the motivation of acquiring this instrument) and the presence of drizzle beneath Sc clouds. We have also noted increased signal return as the NBL forms, and speculate that the swelling of hygroscopic aerosols produces this signal. In fact, the enhanced lidar backscatter in the lowest 200-300 m in Fig. 4 closely parallels the temperature (and hence relative humidity) profile. This signal is also apparent in Fig. 4, but is not as dramatic as patterns observed on other nights.

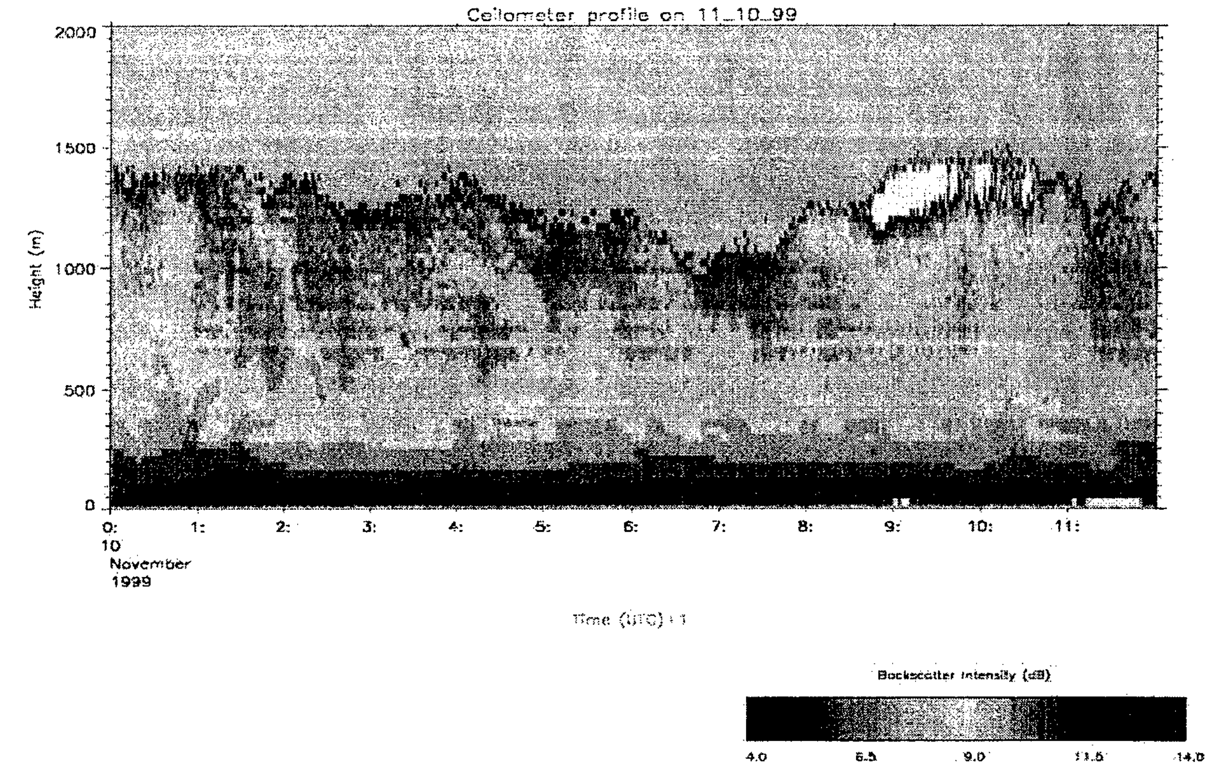

Fig. 4. Time vs. height section of lidar ceilometer return power.

Doppler sodar

The 2 kHz monostatic (and phased array) Doppler sodar is sensitive to the temperature structure function, C_T^2, and hence shows the location and relative strength of low-level inversions. For the 10 November case, the inversion is confined to the lower 200-300 m and exhibits some minor variability in height. Winds are measured at 20-m height intervals, beginning at 40 m. During the night of 10 November, winds veered from SE to WSW over the lowest 200-250 m.

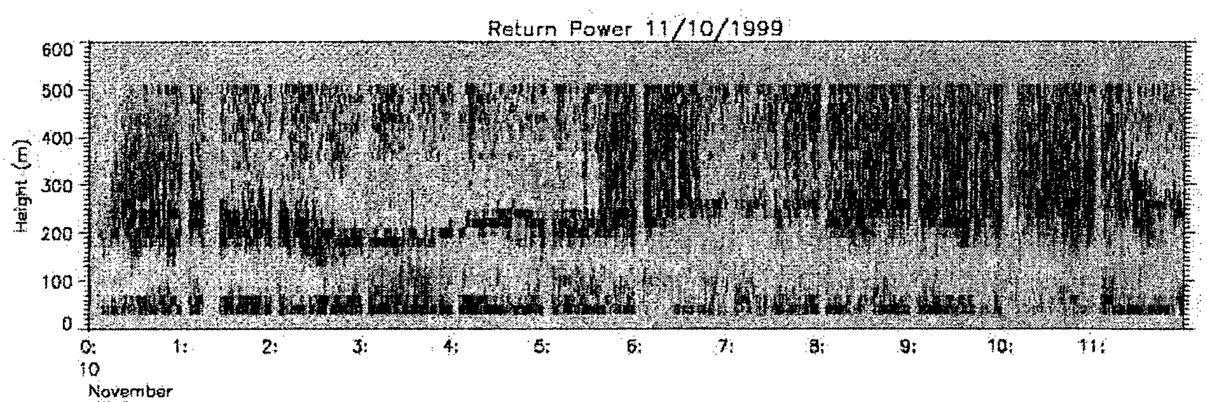

Fig. 5. Time vs height section of sodar return power.

4. Equipment additions and planned future research activities

Using the existing MIPS capabilities as leveraging, we were successful in acquiring funds from the NSF Major Research Instrumentation program to purchase a 12-channel passive microwave radiometer, capable of measuring profiles of temperature and water vapor up to 10 km, with greatest resolution at low levels. This instrument will provide valuable thermodynamic measurements within and above the convective and stable boundary layers. The MIPS is gaining national recognition as a valuable resource, and we are planning to utilize this system in future NBL measurement campaigns centered on Redstone Arsenal during all seasons. When the WSR-74C radar becomes available (and upgraded), it will be used to monitor low-levels flows in the NBL and CBL. We may also have access to a 2 μm Doppler lidar owned by NASA/MSFC in future ABL investigations.

The MIPS is being used to investigate boundaries under current NSF funding, and is being incorporated into the scientific planning of national field programs such as CAMEX 4 (2001, NASA), IHOP-2002 (International H_2O experiment, NSF) and BAMEX (Bow echo and mesoscale convective vortex experiment, 2003).

The mesoscale network centered on Redstone Arsenal is expected to expand as funds and resources from other programs become available.

Appendix: List of primary equipment and components purchased under this project.

Tower sensors (from Campbell Scientific)	
Data Logger, CR10X	$1,046.40
Sensor, HMP45C T/RH with 60 ft cable	$504.00
Wind monitor, RM Young 05103, 60 ft.	$744.00
Misc. (cables, shiels, hardware)	$829.00
WSR-74C upgrade components	
Piraq 2 radar board	$8,240.00
DMC-1728 Axis motion controller	$1,795.00
Software cable, interconnect module	$710.00
Microwave comm, 200TSE short range	$8,260.00
Exabyte tape drives (2)	$1,036.82
Personal computers	$3,423.00
Ceilometer components (Vaisala)	
Ceilometer	$25,900.00
Laptop computer	$1,950.00
Zip drive and disks	$260.00
Hard drive	$290.00
Electrical supplies	$600.00
915 MHz profiler components (Radian)	
915 MHz profiler antenna	$24,000.00
DSP card	$1,500.00
Radar processor	$2,000.00
Antenna retrofit	$1,700.00
Testing and integration	$15,000.00
Software upgrade	$5,000.00
Doppler sodar components (Radian)	
Sodar, Echosonde 600 PA	$52,500.00
Sodar stand	$4,000.00
Integration	$7,000.00
Other	
2/23/98 Travel costs	$415.65
Personal computers (data analysis/archival)	$6,020.00